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Conservation status of eulachon in the California Current

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Abstract

Eulachon (*Thaleichthys pacificus*), an anadromous smelt in the Northeast Pacific Ocean was examined for listing under the USA's Endangered Species Act (ESA). A southern Distinct Population Segment (DPS) of eulachon – that occurs in the California Current and is composed of numerous subpopulations that spawn in rivers from northern California to northern British Columbia – was identified on the basis of ecological and environmental characteristics, and to a lesser extent, genetic and life history variation. Although the northern terrestrial boundary of this DPS remains uncertain, our consensus opinion was that this northern boundary occurs south of the Nass River and that the DPS was discrete from more northern eulachon, as well as significant to the biological species as a whole and thus is a 'species' under the ESA. Eulachon have been nearly absent in northern California for over two decades, have declined in the Fraser River by over 97% in the past 10 years, and are at historically low levels in other British Columbia rivers in the DPS, and nearly so in the Columbia River. Major threats to southern eulachon include climate change impacts on ocean and freshwater habitat, by-catch in offshore shrimp trawl fisheries, changes in downstream flow timing and intensity owing to dams and water diversions, and predation. These threats, together with large declines in abundance, indicate that the southern DPS of eulachon is at moderate risk of extinction throughout all of its range. The southern DPS was listed as threatened under the ESA in May 2010 – the first marine forage fish to be afforded these statutory protections, which apply only to waters under U.S. jurisdiction.

Keywords Climate change, Endangered Species Act, forage fish, osmerid smelt, *Thaleichthys pacificus*

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Introduction

Eulachon (*Thaleichthys pacificus*, Osmeridae) is an anadromous smelt that ranges from northern California to the southeastern Bering Sea coast of Alaska (Hay and McCarter 2000; Willson *et al.* 2006; Moody and Pitcher 2010) (Fig. 1). The declining abundance of eulachon in the southern portion of its range led the Cowlitz Indian Tribe to petition (Cowlitz Indian Tribe 2007) the National Marine Fisheries Service (NMFS) to list eulachon in Washington, Oregon, and California as a threatened or endangered species under the USA's Endangered Species Act (ESA). The present contribution is a review of the scientific information used by NMFS in its ESA listing decision for eulachon.

An ESA status review involves answering two key questions: (i) is the entity in question a 'species' as defined by the ESA? and (ii) if so, is the 'species' at risk of extinction throughout all or a significant portion of its range? An 'ESA species' may consist of a taxonomically named species or subspecies, or in the case of vertebrate organisms, a distinct population segment (DPS). A DPS must be 'discrete' from the remainder of the species to which it belongs and 'significant' to the species as a whole (USFWS and NMFS 1996); however, if multiple DPSs cannot be identified, then the 'ESA species' is the taxonomic species or subspecies. A population may be considered discrete if it is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological or behavioural factors (genetic or morphological differences may provide evidence of this separation). If a population segment is considered discrete, its biological and ecological significance is then evaluated on the basis of: (i) whether it occurs in an ecological setting unusual or unique for the species; (ii) whether its loss would result in a significant gap in the species' range; (iii) whether it represents the only surviving indigenous occurrence of the species; or (iv) whether it differs markedly from other populations of the species in its genetic characteristics (U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) 1996). Previous application of the above 'discreteness' and 'significance' criteria to marine and anadromous fishes has resulted in DPSs that consist of numerous genetically and demographically identifiable stocks or subpopulations, irregardless of whether the DPS was eventually considered at risk of extinction (see list at http://www.nmfs.noaa.gov/pr/species/esa/fish.htm, accessed January 2011) or not at risk (Gustafson *et al.* 2000, 2006; Stout *et al.* 2001; Adams *et al.* 2007; Carls *et al.* 2008). In line with NMFS policy, we placed the emphasis on biological and ecological information in defining an 'ESA species' and note that although biological units often span international boundaries, ESA listings have regulatory effect only within the United States or waters within U.S. jurisdiction.

Information evaluated during an ESA extinction risk assessment can generally be grouped into two categories: (i) demographic information (see McElhany *et al.* 2000), and (ii) threats. In our review, overall extinction risk of the ESA species unit was assessed as either 'at high risk,' 'at moderate risk,' or 'not at risk' of extinction. A species or DPS that is at 'high risk' of extinction is at or near a level of abundance, productivity, spatial structure, and/or diversity that places its persistence in question. A high-risk species or DPS is highly vulnerable to extinction owing to stochastic variability, depensatory processes, and/or clear and present threats. Conversely, a species or DPS is at 'moderate risk' of extinction if it exhibits a trajectory indicating that it is more likely than not to be at a high risk of extinction owing to projected threats and/or declining trends in abundance, productivity, spatial structure, or diversity. Conservation biologists commonly use a 100-year time frame in their extinction risk evaluations (Morris *et al.* 1999), and we adopted this period in this review. As articulated by McElhany *et al.* (2000), a 100-year time frame is 'a reasonable compromise: it is long enough to encompass many long-term processes, but short enough to feasibly model or evaluate.'

The ESA requires that the best scientific and commercial information available be applied in determining the listing status of a species or DPS. For relatively poorly monitored species such as eulachon, this standard results in a risk assessment process that requires the gathering and use of information from a wide variety of sources on the

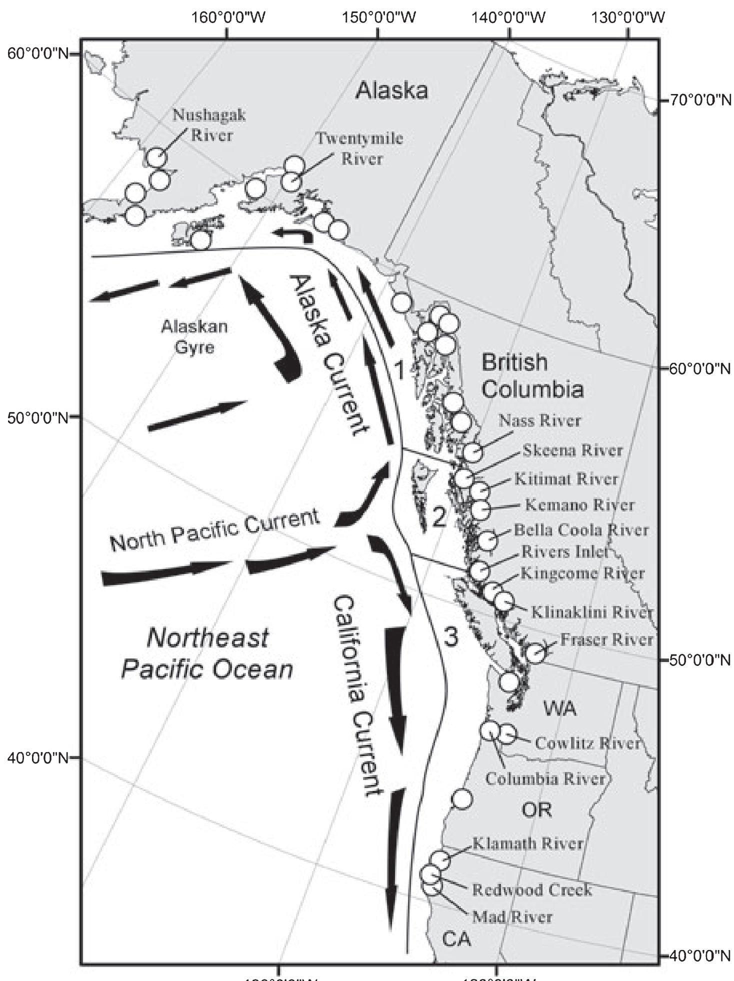

Figure 1 Schematic presentation showing eulachon spawning rivers (open circles), rivers mentioned in the text, oceanographic currents, oceanic domains (Ware and McFarlane 1989) and coastal provinces (Longhurst 2006) in the Northeast Pacific Ocean. 1–Alaska Coastal Downwelling Province (aka Coastal Downwelling Domain), 2–Transition Zone, and 3–California Current Province (aka Coastal Upwelling Domain), WA–Washington, OR–Oregon, CA–California.

biology, ecology, distribution, abundance, status and trends of a species, including information that may be anecdotal, derived from oral interviews or found in historical documents (see USFWS and NMFS 1994), and requires making recommendations based on imperfect and incomplete information.

Eulachon life history

Adult eulachon typically spawn at age 2–5, when they are 160–250 mm fork length, in the lower portions of rivers that have prominent spring peak flow events or freshets (Hay and McCarter 2000; Willson *et al.* 2006) (Fig. 1). Many rivers within the range of eulachon have consistent yearly spawning runs; however, eulachon may appear in other rivers only on an irregular or occasional basis (Hay and McCarter 2000; Willson *et al.* 2006). The spawning migration typically begins when river temperatures are between 0 and 10 °C, which usually occurs between December and June. Run timing and duration may vary interannually, and multiple runs occur in some rivers (Willson *et al.* 2006). Most eulachon are semelparous. Fecundity ranges from 7000–60 000 eggs, which are approximately 1 mm in diameter. Milt and eggs are released over sand or coarse gravel. Eggs become adhesive after fertilization and hatch in 3–8 weeks depending on temperature. Newly hatched larvae are transparent, slender and about 4–8 mm total length. Larvae are transported rapidly by spring freshets to estuaries (Hay and McCarter 2000; Willson *et al.* 2006) and juveniles disperse onto the continental shelf within the first year of life (Hay and McCarter 2000; Gustafson *et al.* 2010). In research trawl surveys, most juvenile eulachon are taken at around 100 m depth in British Columbia (Hay and McCarter 2000) and between 137 and 147 m off the U.S. West Coast (defined as Washington, Oregon and California) (see references in Gustafson *et al.* 2010). In the western Gulf of Alaska, eulachon (58–205 mm standard length) concentrate over the shelf in proximity to sea valleys (Wilson 2009) where, in contrast to other small neritic fishes, they feed almost exclusively on euphausiids (Wilson *et al.* 2009).

Eulachon have great ceremonial, nutritional, medicinal and economic importance for local indigenous peoples (Mitchell and Donald 2001; see references in Gustafson *et al.* 2010). In many areas, eulachon returned to the rivers in the late winter and early spring when other food supplies were scarce and were known, for this reason, as the 'salvation fish.' The earth renewal religion rituals of the Oregon-California borderland people were associated with these types of 'first fruit' local environment sites (Whaley 2005). North of the Fraser River, the fat of the eulachon was often rendered into oil or 'grease.' The abundance of eulachon and the value of the grease as a trade item with groups that lacked access to eulachon fishing sites meant that eulachon were second only to salmon in importance as a natural resource to many local indigenous peoples (Mitchell and Donald 2001).

What is the 'species' unit for ESA listing?

Review of 'species' data

We evaluated ecological and environmental characteristics, biogeography, spawn timing, spawning distribution, genetic variation, morphometrics, meristics and demographic data (growth rate, fecundity, etc.) for evidence of DPS discreteness and significance (Gustafson *et al.* 2010). Factors that were particularly useful for identification of an 'ESA species' that incorporates eulachon that spawn in rivers in Washington, Oregon and California are summarized below.

Ware and McFarlane (1989) identify three principal fish production domains in the northeast Pacific Ocean: (i) a northern Coastal Downwelling Domain, (ii) a southern Coastal Upwelling Domain, and (iii) a Central Subarctic Domain (also known as the Alaskan Gyre). Similarly, Longhurst (2006) recognizes an Alaska Downwelling Coastal Province and a California Current Province (Fig. 1), within the Pacific Coastal Biome, based mainly on differences in regional physical processes that act upon regional patterns of nutrient enrichment and phytoplankton growth. Longhurst (2006) places the boundary between the Alaska Coastal Downwelling Province and the California Current Province between Haida Gwaii (formerly known as the Queen Charlotte Islands) at 53°N and the northern end of Vancouver Island at 47–48°N latitude, where the eastward flowing North Pacific Current encounters the North American continent and bifurcates to form the north-flowing Alaska Current and south-flowing California Current (Fig. 1). A widely recognized Transition Zone (Fig. 1) with indistinct and seasonally variable boundaries occurs between the Alaska Coastal Downwelling and California Current provinces (Ware and McFarlane 1989; BC Ministry of Sustainable Resource Management 2002). The strong ecological and environmental break that occurs between the California Current and Alaska Coastal Downwelling (Alaska Current) provinces were viewed as providing strong support for discreteness of eulachon in these two domains.

Population structure within the species is probably affected by imprinting on and homing to natal areas, but the mechanisms are poorly understood. McCarter and Hay (McCarter and Hay 1999; Hay and McCarter 2000; Hay 2002) suggest that eulachon likely home to estuaries rather than to individual natal rivers owing to the small size and short freshwater residence of the larvae (McCarter and Hay 1999; Hay and McCarter 2000; Hay 2002). Geographic variation in eulachon spawn timing has been cited as evidence of local adaptation (Hay and McCarter 2000), but there is no clear latitudinal or other pattern apparent in eulachon spawn timing (Hay *et al.* 2002), and the presence of multiple spawning runs in some rivers and extended spawning duration in others also makes it difficult to discern consistent patterns (Gustafson *et al.* 2010). In general, eulachon spawning occurs later in northern rivers; for example, eulachon enter the Columbia River and begin to spawn in December and January, as compared to south-central Alaskan rivers where spawning begins as late as May or June (Gustafson *et al.* 2010). However, eulachon may spawn as early as January in rivers on the Copper River Delta of Alaska and as late as May in northern California. These differences in spawn timing result in some populations spawning when water temperatures are as low as 0–2 °C (Nass River; Langer *et al.* 1977), whereas other populations experience spawning temperatures from 4 to 10 °C (Cowlitz River; Smith and Saalfeld 1955) (Fig. 1). Thus, eulachon spawning in rivers on the north coast of British Columbia (e.g., Nass River) typically experiences significantly colder temperatures at spawning (often spawning under ice) compared to eulachon spawning to the south, particularly in the Klinaklini, Fraser and Columbia rivers (Fig. 1) (Hay and McCarter 2000).

Coastwide, there appears to be an increase in both mean length and weight of eulachon at maturity with an increase in latitude (Gustafson *et al.* 2010). Mean fork length and weight at maturity range from upwards of 215 mm and 70 g in the Twentymile River, Alaska to 175 mm and 37 g in the Columbia River. However, this latitudinal cline in body size is typical of many vertebrate ectotherms where higher rearing temperatures result in a significant reduction in body size at age (Lindsey 1966; Atkinson 1994), and in the case of eulachon these morphological differences were not considered compelling evidence of biological discreteness.

Studies of genetic population structure in eulachon have analysed variation in mitochondrial DNA (mtDNA) haplotypes (McLean *et al.* 1999) and in several microsatellite DNA loci (McLean and Taylor 2001; Beacham *et al.* 2005). The most extensive available study of eulachon, Beacham *et al.* (2005), examined variation in 14 microsatellite DNA loci from eulachon collected at nine sites ranging from the Columbia River to Cook Inlet, Alaska. Genetic differentiation was observed among all comparisons of the nine populations in the study at statistically significant levels, and F_{ST} values for pairs of populations ranged from 0.0014 to 0.0130 (Beacham *et al.* 2005). However, when samples collected in multiple years were analysed from populations in the Bella Coola and Kemano rivers (2 years of sampling) and also in the Nass River (3 years of sampling), year-to-year genetic variation within each of these British Columbia coastal river systems was similar to the level of variation among the rivers (Beacham *et al.* 2005), which suggests that some patterns observed among rivers may not be temporally stable. Nevertheless, a cluster analysis of genetic distances showed genetic affinities among the populations in the Fraser, Columbia and Cowlitz rivers and also among the Kemano, Klinaklini and Bella Coola rivers (Fig. 1). In particular, there was evidence of a genetic discontinuity north of the Fraser River, with Fraser and Columbia/Cowlitz samples being approximately 3–6× more divergent from samples further to the north than they were to each other. Beacham *et al.* (2005) suggested that the pattern of eulachon genetic differentiation was similar to that typically found in marine fishes, but less than that observed in most Pacific salmon species.

Conclusions on the ESA species question

To allow for expressions of the level of uncertainty in identifying an 'ESA species' that incorporates eulachon from the states of Washington, Oregon and California, we adopted a 'likelihood point' method where each status review team member (see author list) had ten 'likelihood' points to distribute among several proposed scenarios. After eliminating several possible scenarios which had no support on our team (see Gustafson *et al.* 2010), four 'ESA species' scenarios were seriously considered. These scenarios and the support – as a percentage of the total available likelihood points – they received were: (i) the entire biological species is the ESA species (12% support); (ii) eulachon from south of the Nass River/Dixon Entrance region of British Columbia through northern California consist of one DPS and eulachon from the Nass River and further north consist of one or more additional DPS(s) (57% support); (iii) eulachon from the Fraser River through northern California consist of one DPS and eulachon from north of the Fraser River consist of one or more additional DPS(s) (27% support); and (iv) there are multiple DPSs of eulachon in Washington, Oregon and California (4% support) (see further details in Gustafson *et al.* 2010).

Thus, our majority opinion was that eulachon from Washington, Oregon and California are part of a DPS, composed of numerous subpopulations, that extends beyond the conterminous United States and that the northern boundary of the DPS occurs in northern British Columbia south of the Nass River (most likely) or in southern British Columbia north of the Fraser River (less likely). A clear northern terrestrial or river boundary for this southern DPS was difficult to identify as we believe this boundary is largely associated with oceanographic, not terrestrial, processes. The identification of a southern DPS of eulachon indicates that at least one, and possibly more than one, additional DPS(s) of eulachon occur north of the California Current Province. It is apparent that the best available scientific information for eulachon is at present inadequate to define a particular 'ESA species' with 100% certainty, as reflected in the percentage distribution of likelihood points among the above-proposed DPS scenarios. We also acknowledge that additional scientific research might result in evidence supporting either subdivision or expansion of the southern DPS boundaries. Factors that support the 'discreteness' of the southern DPS include the strong ecological and environmental break that occurs between the California and Alaska currents; apparent geographic differences in temperature at the time of spawning between eulachon in river basins in the southern DPS compared to those further north; and genetic data that suggest Fraser and Columbia River eulachon are discrete from more northern eulachon, although further genetic studies are needed to clarify these relationships. The strong ecological and environmental break that occurs between the California Current and Alaska Current was also an important factor for identifying DPS structure in previous ESA status reviews of Pacific cod (Gustafson *et al.* 2000), killer whales (Krahn *et al.* 2004) and Southeast Alaska Pacific herring (Carls *et al.* 2008).

In evaluating the 'significance' criteria for the southern DPS, evidence for a significant break in ecological setting (significance criterion (i) and evidence that loss of a discrete population within the California Current Province would result in a significant gap (or reduction) in the range of the overall species (significance criterion (ii) were most important. Although we believe the genetic data provided evidence for discreteness (lack of gene flow) of eulachon from the Fraser and Columbia rivers, we do not believe that the magnitude of genetic distinctiveness observed could be characterized as compelling evidence that this unit 'differs markedly from other populations of the species in its genetic characteristics' (significance criterion (iv). We did not attempt to identify additional DPSs to the north of the southern DPS of eulachon as these designations have statutory significance in the USA, and our mandate was only to identify an 'ESA species' that includes eulachon from the petitioned area of Washington, Oregon and California.

What is the level of 'extinction risk'?

Although humans have exploited eulachon populations for centuries, the historically high abundance of the resource and its low commercial value resulted in limited regulation of past commercial and recreational fisheries, limited recording of past catches, and until recently, a lack of assessment surveys of spawning abundance. For a few eulachon populations, spawning stock biomass (SSB) has been estimated since 1993 (Table 1), but earlier population sizes can only be inferred from catch statistics and anecdotal information. The lack of fishery-independent surveys prior to 1993 made it very difficult to quantify trends in eulachon abundance. Inferring population status or even trends from yearly changes in catch statistics requires assumptions that are seldom met; including similar fishing effort and efficiency, assumptions about the relationship of the harvested portion to the total portion of the stock, and statistical assumptions such as random sampling. However, in many parts of the

Table 1 Quantitative (biomass or spawner count) and qualitative (anecdotal descriptions) assessments of eulachon run strength in British Columbia river basins within the southern Distinct Population Segment of eulachon. SSB, spawning stock biomass; t, metric ton.

Year	Fraser River SSB (t)[a]	Klinaklini River (t)	Kingcome River (t)	Rivers Inlet (no. of fish)	Bella Coola River (t)	Kemano River	Kitimat River (no. of fish)	Skeena River (t)
1991	–	–	–	–	–	–	Last strong run[f]	–
1992	–	–	–	–	–	–	–	–
1993	–	–	–	–	–	–	514 000[b]	–
1994	–	–	–	–	–	–	527 000[b]	–
1995	302	40[b]	–	–		–	–	–
1996	1911	–	–	–	Last large run[b]	–	440 000[b]	–
1997	74	–	14[b]	–		–	–	3[h]
1998	136	–	–	–	Average run[b]	–	Non-existent[c]	Very few[b]
1999	418	–	–	No run[c],	Small run[c] Run failed[b]	Negligible[c]	Non-existent[c]	Very few[b]
2000	130	None or poor[c] Very low[d]	No run[c]	No run[c]	No run[d]	Low[c]	Very low in 2000[d]	Little activity observed[d]
2001	609	–	Improved run[b]	No catch[b]	0.039[e]	Low catch[b]	–	–
2002	494	–	Good run[b]	No catch[b]	≈0.050[e]	Low catch[b]	–	–
2003	266	–	Poor run[b]	No catch[b]	0.016[e]	–	Good[d]	–
2004	33	Low returns[b]	Poor run[b]	No catch[b]	0.007[e]	Good spawning success[f]	–	–
2005	16	Low returns[b]	Average run[b]	2700[b]	–	Almost none returned[f]	–	Good run[b]
2006	29	–	Run absent[b]	23 000[b]	Run virtually gone[d]	No significant returns[f]	<1000[b]	Virtually no run[b]
2007	41	Very good run[b]	Small returns[b]	–	–	In estuary but did not ascend the river[b], very low return[f]	Small run of short duration[g]	–
2008	10	–	–	–	–	Almost no spawning eulachon returned[f]	–	–
2009	14	–	–	–	–	–	–	–
2010	4	–	–	–	–	–	–	–

[a]Data online at http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/herspawn/pages/river1-eng.htm (last accessed February 2011); [b]Moody and Pitcher (2010); [c]Hay and McCarter (2000); [d]Pickard and Marmorek (2007); [e]Moody (2007); [f]Rio Tinto Alcan (2005–2009); [g]Kitamaat Village Council (2007); [h]Lewis (1997).

DPS, catch statistics provide the only available quantitative data source that defines the relative abundance of eulachon.

Northern California

Large spawning aggregations of eulachon were reported to have once regularly occurred in the Klamath River (Fry 1979; Moyle *et al.* 1995; Larson and Belchik 1998; Moyle 2002) and on occasion in the Mad River (Moyle *et al.* 1995; Moyle 2002) and Redwood Creek (Moyle *et al.* 1995) in northern California (Fig. 1). The available information was most readily interpreted as indicating that noticeable, regularly returning runs of eulachon once occurred in the Klamath River; however, small numbers of fish have been observed occasionally (e.g., six in January 2007) during the past several decades (see references in Gustafson *et al.* 2010).

Columbia River

Although the magnitude of past commercial fisheries landings in the Columbia River and its tributaries establish that this basin once supported the largest eulachon run in the world (Hay and McCarter 2000), scientific estimates of SSB or number of spawning fish are unavailable. Commercial fisheries were in operation by 1867 and landings were first recorded in 1888 (see Gustafson *et al.* 2010) (Fig. 2). Although not useful for estimating an accurate trend, the long-term landings data do indicate that commercial catch levels were consistently high [>500 metric tons (t) and often > 1000 t] for three-quarters of a century from about 1915 to 1992 (Fig. 2). Landings declined greatly to 233 t in 1993 and to an average of less than 40 t between 1994 and 2000. From 2001 to 2004, landings increased to an average of 266 t, before falling to 8 t or less from 2005 to 2010 (Fig. 2). Fishing restrictions were instituted in 1995, so low landings after that time are in part owing to these restrictions. Nonetheless, the low landings in the fishery subsequent to 1993 (Fig. 2) are generally accepted as indicating that a marked decline in the abundance of the stock occurred (Bargmann *et al.* 2005; JCRMS 2008), and there is no evidence that the Columbia River subpopulation has returned to its pre-1993 level. Ethnographic and historical evidence indicates that a past population decline and subsequent recovery of eulachon occurred in the Columbia River Basin during the 1830s to 1860s (see compilation of historical sources in Gustafson *et al.* 2010). However, the present period of population decline is very different from this past event in that every subpopulation of the DPS is affected, and the decline is not confined to the Columbia River subpopulation.

Fraser River

The Fraser River SSB is the longest running fisheries-independent abundance estimator of spawning biomass for any subpopulation in the DPS (Table 1). SSB is generated from counts of eggs and larvae in plankton tows, combined with river discharge rates, and relative fecundity (eggs produced per gram of eulachon) to estimate metric tons of spawning adults (Hay *et al.* 2002). Over the most recent three-generation time of approximately 10 years, these data indicate that the overall biomass of the Fraser River eulachon population has declined by over 97% (2000, 130 t; 2010, 4 t) (Table 1). Given mean weight estimates of Fraser River eulachon (40.6 g; Hay *et al.* (2002)), these biomass declines represent a reduction in the number of adult eulachon spawning in the Fraser River from about 3.2 million to less than 100 000 over the past 10 years. Under the International Union for Conservation of Nature (IUCN) decline criteria, a reduction in population size of this magnitude would place Fraser River eulachon in the IUCN critically endangered category (IUCN 2001, 2010).

Commercial fishery landings for the Fraser River were first recorded in 1881 and averaged about

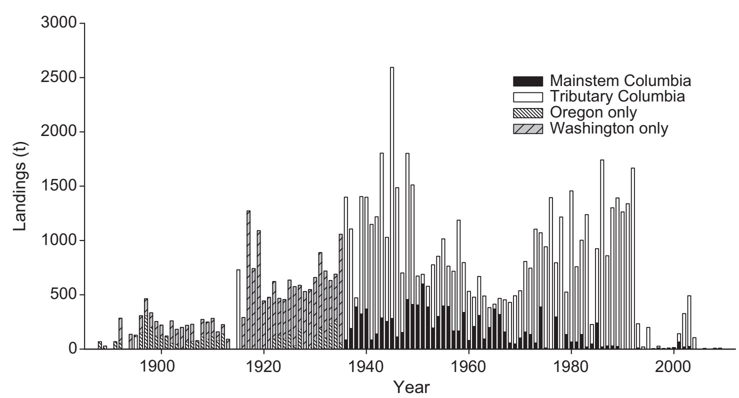

Figure 2 Eulachon landings in Columbia River and tributaries commercial fishery (1888–2010). Landings occurred in 1890; however, values are too small to be evident on the graph. Landings occurred in 1893 and 1914, based on newspaper and periodical sources, but official state records have not been located. Data for 1888–1935 from annual reports of the fisheries departments of Oregon and Washington state (see Gustafson *et al.* (2010) for a complete list); for 1936–37 from Cleaver (1951); for 1938–2000 from WDFW and ODFW (2001); for 2001–2009 from JCRMS (2009); and for 2010 from online source at http://www.dfw.state.or.us/fish/OSCRP/CRM/landings/10/DISTR_Zones1-5_smelt_2010.pdf (last accessed February 2011). Commercial fisheries were closed in 2011.

83 t between 1941 and 1996 (Fig. 3). Past landings were largely driven by market demand (Moody and Pitcher 2010) and indicated only that eulachon were generally present at harvestable abundance levels in the Fraser River during this time period. All First Nations, commercial and recreational fisheries were closed on the Fraser River by 2005 because of conservation concerns, and the stock 'has failed to recover from its collapse' (DFO 2007).

Other British Columbia rivers

In other eulachon spawning rivers in British Columbia, there are few scientifically obtained abundance data available (Table 1), and much of the known information is anecdotal in nature. However, the available SSB data (Table 1), available landings records (Fig. 3), extensive ethnographic literature and anecdotal information (see Gustafson *et al.* 2010) indicate that eulachon in Rivers Inlet (Wannock, Chuckwalla, Kilbella and Clyak rivers) and in the Klinaklini, Bella Coola, Kemano, Kitimat and Skeena rivers (Fig. 1) were almost certainly present in larger annual runs in the past and that current run sizes of eulachon appear inconsistent with the historic level of 'grease' (rendered eulachon oil) production extensively documented in the ethnographic literature (Macnair 1971; Suttles 1990; Moody and Pitcher 2010).

Recent abundance surveys (Table 1) indicate that several subpopulations may be at risk from Allee effects, wherein small populations may suffer low reproductive success because of increased difficulty finding mates, loss of genetic diversity and greater susceptibility to catastrophic events. Of particular concern are recent spawning stock estimates of only 2700 to 23 000 individual spawners in the Rivers Inlet subpopulation (Table 1), the inability to observe eulachon in large numbers in the Kemano River since 2004 (Moody and Pitcher 2010), and the decline in the Kitimat River from annual run sizes of >500 000 individuals in the mid-1990s to <1000 individuals in 2006 (Moody and Pitcher 2010). In addition, available catch records and anecdotal information indicate that Skeena River eulachon were present in larger annual runs in the past – runs that at one time supported a large fishery (Fig. 3). However, anecdotal information (Table 1) indicates that recent returns of eulachon to the Klinaklini River have improved from a low point in 2004–2005, so the status of this population is not entirely clear.

Offshore abundance

Two fisheries-independent indices of juvenile biomass were available that indicate status of current offshore stock mixtures: 1) a West Coast Vancouver Island eulachon biomass index and 2) a Queen Charlotte Sound eulachon biomass index (Fig. 4). Although biomass estimates of eulachon off the U.S. West Coast are available for 1995, 1998 and 2001 (see Gustafson *et al.* 2010), there are no more recent fisheries-independent surveys available for eulachon in this area. The biomass indices of juvenile eulachon in the above offshore surveys (Fig. 4) are one to two orders of magnitude greater than known or suspected freshwater eulachon SSB in the DPS (Table 1). The reasons for this apparent discrepancy are not fully understood; however, these estimates are 'indices' based on by-catch of eulachon in shrimp trawl surveys and not absolute

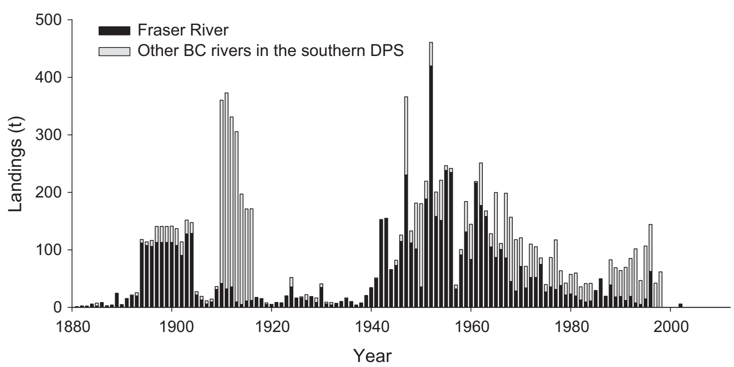

Figure 3 Available commercial and First Nations subsistence eulachon fisheries landings in British Columbia river basins within the southern Distinct Population Segment of eulachon. Data from Parliament of Canada (1881–1916), Canadian Bureau of Statistics (1917–1941), Hay (2002) and Lewis *et al.* (2002).

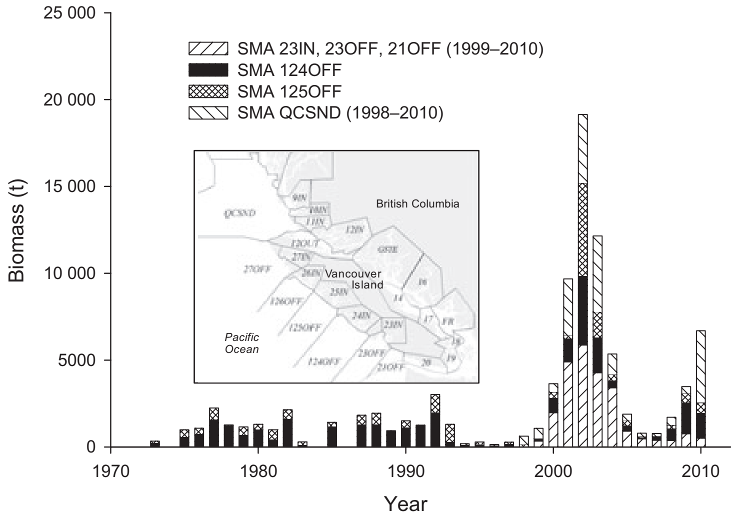

Figure 4 Eulachon biomass indices within various Shrimp Management Areas (SMAs) off the west coast of Vancouver Island and in Queen Charlotte Sound (QCSND) (see map inset). Data from DFO (2010) and DFO Shrimp Survey Bulletins (2000–2010; available at http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/Shellfish/shrimp/surveys/surveys.htm? (last accessed February 2011)).

biomass estimates, production from two or more year classes of eulachon are incorporated into the index estimates, and these two cohorts may experience substantial mortality prior to their freshwater spawning migration.

Regional and species wide threats

Unlike some ESA-listed species that face a single primary threat, eulachon face numerous threats throughout various stages of their life cycle. We quantitatively ranked the severity of each of 16 potential threats as very low, low, moderate, high or very high in four subareas (Klamath, Columbia, Fraser and other British Columbia rivers) of the southern DPS of eulachon (see details in Gustafson *et al.* 2010). Results of this qualitative threats assessment indicated that climate change impacts on ocean conditions was the most serious threat to the persistence of eulachon in all areas of the DPS. Climate change impacts on freshwater habitat and eulachon by-catch in offshore shrimp fisheries were also ranked among the top four threats in all areas of the DPS. Dams and water diversions in the Klamath and Columbia rivers and predation in the Fraser and British Columbia coastal rivers filled out the last of the top four threats. Here, we focus on these five threats that ranked as moderate to very high severity in our analysis (see Gustafson *et al.* 2010).

Climate change impacts on ocean conditions

The Independent Scientific Advisory Board (ISAB) (2007) reported that oceanographic records show a warming trend in sea surface temperatures and a decreasing trend in salinities over the past 50 years within the subarctic Northeast Pacific. However, climate warming impacts on eulachon may extend beyond actual warming water temperatures. Primary productivity in the northern California Current ecosystem is fuelled by wind-driven upwelling of cold, nutrient-rich, deep waters to the surface (Bakun 1990; Ware and Thomson 1991; ISAB 2007). Along the coasts of British Columbia, Washington and Oregon, this ocean upwelling is dependent on strong northerly or equator-ward winds which are generated by pressure gradients between high barometric pressure that develops over the cool ocean and a low-pressure thermal cell that develops over the heated land mass (Bakun 1990). It is hypothesized that climate warming will intensify these thermal land–sea differences, since land areas are predicted to warm twice as fast as the oceans, and should lead to more intense coastal upwelling in the California Current Province (Bakun 1990). More intense upwelling should lead to increased primary productivity in the California Current, but the peak upwelling season is predicted to occur up to 1 month later and primarily from June to September in the northern portion of the

California Current (Snyder *et al.* 2003; Barth *et al.* 2007; ISAB 2007). A shift in peak upwelling to 1 month later than normal may result in a temporal trophic mismatch between juvenile eulachon entry into the ocean, and the presence of preferred prey organisms whose productivity is dependent on the early initiation of upwelling conditions.

Ocean conditions off the Pacific Northwest in 2005 were similar to what may be expected if climate change predictions for the next 100 years are accurate. Barth *et al.* (2007) noted that there was a '1-month delay in the 2005 spring transition to upwelling-favorable wind stress in the northern California Current,' and during May to July, upwelling-favourable winds were at their lowest levels in 20 years and 'nearshore surface waters averaged 2 °C warmer than normal.' Eulachon returns to spawning rivers in the southern DPS were poor during this period of unfavourable ocean conditions from 2004 to 2008 (Joint Columbia River Management Staff (JCRMS) 2008) and may portend how eulachon will respond to warming ocean conditions.

Climate change impacts on freshwater habitat

Analyses of temperature trends for the U.S. Pacific Northwest (Mote *et al.* 1999); the maritime portions of Oregon, Washington, and British Columbia (Mote 2003a); and the Puget Sound–Georgia Basin region (Mote 2003b) have shown that air temperature increased 0.8, 0.9 and 1.5 °C in these respective regions during the twentieth century. Results from 10 different climate model simulations that assume two different greenhouse gas emission scenarios predict a 1 to 6 °C increase in air temperature for the Pacific Northwest by 2100 (ISAB 2007). The Independent Scientific Advisory Board (ISAB) (2007) summarized projected changes associated with climate change in the Columbia Basin and stated that 'Warmer temperatures will result in more precipitation falling as rain rather than snow; snow pack will diminish, and stream flow timing will be altered; and peak river flows will likely increase.'

Because many eulachon rivers are fed by extensive snowmelt or glacial runoff, elevated temperatures, changes in snow pack and changes in the timing and intensity of stream flows will likely have impacts on eulachon. In most rivers, eulachon typically spawn well before the spring freshet, near the seasonal flow minimum, and this strategy typically results in egg hatch coinciding with peak spring river discharge. The expected alteration in stream flow timing may cause eulachon to spawn earlier or be flushed out of spawning rivers at an earlier date. Early emigration, together with the anticipated delay in the onset of coastal upwelling (see above), may result in a mismatch between entry of juvenile eulachon into the ocean and coastal upwelling, which could have a negative impact on marine survival of eulachon during this critical transition period. There are already indications, perhaps in response to warming conditions or altered stream flow timing that adult eulachon are returning earlier in the season than they did historically to several rivers within the southern DPS (Moody and Pitcher 2010).

By-catch in shrimp fisheries

Eulachon occur as by-catch in shrimp trawl fisheries off the coasts of Washington, Oregon, California and British Columbia (Hay *et al.* 1999a,b; Olsen *et al.* 2000; NWFSC 2008). The shrimp trawl fishery that began in 1996 in Queen Charlotte Sound was closed in mid-season 1999 in response to a high eulachon by-catch and low eulachon returns to local rivers, and has not re-opened because of 'concerns for central coast eulachon stocks' (DFO 2009). If eulachon by-catch in shrimp trawl fisheries off the west coast of Vancouver Island exceeds 1% of the eulachon abundance index in this area, then further restrictions or a complete closure of the fishery may be imposed (DFO 2010). Prior to 2003, when use of by-catch reduction devices (BRDs) became mandatory in all the U.S. West Coast shrimp trawl fisheries, 32–61% of the total catch in the ocean shrimp (*Pandalus jordani*, Pandalidae) fishery in Oregon consisted of non-shrimp biomass, including various species of smelt (Hannah and Jones 2007). As of 2005, following required implementation of BRDs, the total by-catch by weight had been reduced to about 7.5% of the total shrimp catch, and osmerid smelt by-catch was reduced to an estimated average of 0.7% of the total catch across all BRD types (Hannah and Jones 2007). Eulachon by-catch rates in the ocean shrimp fishery with BRDs installed north of 40°10′N latitude were 0.0004 (NWFSC 2008) in 2007 and 0.0008 in both 2008 and 2009 (NWFSC 2009, 2010). Given coastwide fleet landings of ocean shrimp (NWFSC 2009, 2010), there was an estimated by-catch in this fishery of 4.7 (Bellman *et al.* 2008), 13.2 and

11.5 t of eulachon in 2007, 2008 and 2009, respectively.

Although mandated use of BRDs has substantially reduced by-catch of fin fish in offshore shrimp trawl fisheries (Hannah and Jones 2007; Frimodig 2008), data on survival of small pelagic fishes such as eulachon after deflection by BRDs are scarce. Studies on other fishes indicate that 'among some species groups, such as small-sized pelagic fish, mortality may be high' and 'the smallest escapees often appear the most vulnerable' (Suuronen 2005). Results of several studies have shown a direct relationship between length and survival of fish escaping trawl nets, either with or without deflecting grids (Sangster *et al.* 1996; Suuronen *et al.* 1996; Ingólfsson *et al.* 2007), indicating that smaller fish with their poorer swimming ability and endurance may be more likely to suffer greater injury and stress during their escape from trawl gear than larger fish (Broadhurst *et al.* 2006; Ingólfsson *et al.* 2007). It is thus difficult to evaluate the true effectiveness of BRDs in a fishery without knowing the survival rate of fish that are deflected by the BRD and escape the trawl net (Broadhurst 2000; Suuronen 2005; Broadhurst *et al.* 2006).

Dams and water diversions

Dams and water diversions can change downstream flow intensity and flow timing, reduce transport of fine sediments and cut off the source of larger sediments like sand and gravel for downstream habitats, all of which can have negative impacts on eulachon productivity. The impact of six hydroelectric dams on the Klamath River, and others on the tributary Trinity River, as well as associated irrigation withdrawals in the upper Klamath River basin, have shifted the spring peak flow of the lower Klamath River from its historical peak in April to its current peak in March, one full month earlier (National Research Council 2004). Similarly, operation of 28 mainstem and about 300 tributary dams and water withdrawals for irrigation has significantly altered the natural hydrologic pattern of the Columbia River (Sherwood *et al.* 1990; Bottom *et al.* 2005). Flow regulation has shifted the peak spring freshet in the Columbia River such that it occurs approximately 2 weeks earlier now than it did prior to 1900, and the magnitude of the spring freshet has also decreased by more than 40% (Bottom *et al.* 2005). These shifts in flow intensity and timing may result in reduced egg and larval survival of eulachon, which are dependent on precise synchronization with river conditions and subsequent availability of preferred juvenile prey species in the ocean.

Predation

Eulachon are a lipid-rich food source for many marine mammals, birds and marine and freshwater fish (Hay and McCarter 2000; Hay 2002; see references in Gustafson *et al.* 2010). Predation on adult eulachon just prior to spawning in estuarine and riverine environments can be very high, and return of eulachon is typically signalled by the impressive number of avian and marine mammal predators that accompany eulachon spawning runs (see review of eulachon predation in Gustafson *et al.* 2010). In addition, recent changes in distribution and abundance of Pacific hake (*Merluccius productus*, Gadidae) may have had a particular impact on eulachon abundance (Hay and McCarter 2000). The offshore Pacific hake stock migrates northward from winter spawning grounds to feed off the coast of the Pacific Northwest in the summer. This stock may account for over 60% of the offshore pelagic biomass in the California Current system (Ware and McFarlane 1995), and recent evidence (Phillips *et al.* 2007) indicates that the feeding migration of Pacific hake may be extending further north within the northern California Current system. In the spring of 1980, nearly 80% of the diet of large Pacific hake (>500 mm) off Oregon consisted of eulachon, whereas eulachon made up 22% of the diet of Pacific hake less than 550 mm in length (Livingston 1983). The large biomass of Pacific hake off the west coast of Vancouver Island in summer may have a significant negative impact on eulachon numbers (Hay and McCarter 2000; Hay 2002).

Conclusions and discussion on the 'extinction risk' question

Using the 'likelihood point' method previously described for our DPS decision, scores for overall extinction risk to the southern DPS of eulachon, throughout all of its range, were heavily weighted to moderate risk, which received 60% of the likelihood points. High risk received 32% and not at risk received 8% of the likelihood points. The following concerns were of particular importance in reaching our majority conclusion of moderate risk. Although eulachon are a relatively poorly monitored species, the available information suggests that: (i) historically large runs of eulachon in northern California rivers declined to nearly undetectable levels over 20 years ago, (ii) eulachon in other areas of the southern DPS experienced an abrupt decline in 1993–1994, and (iii) two large spawning populations in the DPS – the Columbia and Fraser rivers – have declined to what appear to be historically low levels in the Fraser River and nearly so in the Columbia River. In addition, recent attempts to estimate actual spawner abundance in some rivers in British Columbia that are known to have supported significant First Nations fisheries in the past have resulted in very low estimates of spawning stock (Table 1). The declines in the Columbia River in the early 1990s appeared to coincide with a decline in eulachon in British Columbia south of the Nass River, suggesting that a common cause, such as changing ocean conditions, was responsible for these declines. Failure to time spawning activity with river conditions conducive to successful fertilization and egg survival, and to the appearance of prey species in the ocean, may be contributing to high rates of environmentally driven egg, larval and juvenile mortality. It is also likely that eulachon (and other similar forage fishes) may be at significant risk at minimum viable population sizes that are a fraction of their historical levels, but are still large compared to what would be considered normal for other ESA-listed species (Dulvy *et al.* 2004).

Conversely, we do not believe eulachon to be currently at high risk of extinction over the entire DPS, as they continue to display a high degree of biocomplexity (e.g., many spawning locations and variation in spawn timing and age-at-maturity) and a medium rate of productivity (based on the species' intrinsic rate of increase, von Bertalanffy growth coefficient, high fecundity, low age at maturity and low maximum age; see Musick *et al.* 2000), which may help buffer stocks from future environmental perturbations. These characteristics likely give eulachon some resilience to extinction – as demonstrated by their ability to rapidly respond to favourable ocean conditions – and served to ameliorate our concerns for individual demographic risks (abundance, spatial connectivity and diversity). This factor weighed heavily in our majority conclusion that the DPS is at 'moderate' rather than 'high risk' of extinction.

The eulachon status review conclusion that the southern DPS of eulachon was at moderate risk of extinction, together with the evaluation of other factors such as existing conservation initiatives (see NMFS 2010), resulted in the southern DPS of eulachon being listed as a threatened species under the ESA in May 2010 (NMFS 2010). Although the range of this DPS extends into Canada, ESA implementing regulations only apply to areas within the United States or waters within U.S. jurisdiction. To date, this ESA listing has resulted in: (i) cessation of all commercial and recreational fisheries in the Columbia River Basin for 2011, (ii) proposed designation of critical spawning habitat within areas under U.S. jurisdiction (NMFS 2011), and (iii) expansion of NMFS's West Coast Groundfish Observer Program to Washington's ocean shrimp trawl fishery to provide additional eulachon by-catch information. In addition, the ESA listing has resulted in the awarding of nearly 3 million U.S. dollars (over a 3-year period) by NMFS to the states of Washington (WA) and Oregon (OR) and the Yurok Tribe (YT) in California and the Cowlitz Indian Tribe (CIT) in Washington to: (i) determine whether eulachon still exist in the Klamath and Mad rivers as well as Redwood Creek in California (YT), (ii) develop and implement a eulachon SSB estimate for the Columbia (WA, OR) and Klamath (YT) rivers, (iii) identify environmental factors influencing spawning run timing and tributary selection (CIT), (iv) conduct egg and larval surveys to identify spawning eulachon distribution (WA, OR, CIT, YT), (v) correlate spawning distribution with habitat quality factors (CIT), (vi) investigate egg mortality potentially caused by sedimentation (CIT), (vii) develop and test modifications to ocean shrimp trawl gear to reduce eulachon by-catch (WA, OR), and (viii) assess spatial and temporal differences in the genetic makeup of eulachon (OR, WA, CIT, YT). Eulachon play an important role in the food web of the California Current ecosystem; if the fundamental biological processes necessary for eulachon to persist in the California Current cease to function effectively, the long-term consequences for other species could also be substantial.

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